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METHOD FOR WINDING A STATOR OF MULTI-PHASE MOTORS

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1                   **METHOD FOR WINDING A STATOR OF MULTI-PHASE MOTORS**

2                   This Application claims the benefit of U.S. Provisional Application  
3                   No. 60/455,976, filed on March 19, 2003.

4                   **BACKGROUND OF THE INVENTION**

5                   The present invention generally relates to multiple phase electric  
6                   motors, and more particularly to the winding of coils during the manufacture of such  
7                   motors.

8                   Conventional brushless permanent magnet servomotor designs that  
9                   are common in the marketplace include 4-pole rotor – 12 slot stator motors; 4 pole –  
10                  24 slot motors; 6 pole – 18 slot motors; and 6 pole – 36 slot motors, for example. An  
11                  illustration of an 18-slot stator 10 is shown in FIG. 1. A typical winding pattern for  
12                  two phases (U and V) of an 18-slot stator is shown in FIGS. 2 and 3. Because of the  
13                  crossovers 12 of coils in the ends of the stator 10, the winding end-turns 14 tend to  
14                  be long and bulky and add considerably to the winding resistance in the winding  
15                  pattern shown in FIG. 2. This reduces the motor torque density. Also, in order to  
16                  produce motors capable of running off servo amplifier bus voltages up to  
17                  approximately 680 V DC, inter-phase insulation paper 16 must be routed between  
18                  the coils of adjacent phases.

1                   To avoid these issues many manufacturers have adapted motor  
2 topologies using single-tooth winding, so that each coil has a span of one lamination  
3 tooth. In order to utilize this topology, the ratio of motor slots to poles (S/P) must lie  
4 in the range of  $0.5 < S/P \leq 1.5$ . Single tooth winding significantly reduces the height  
5 of the winding heads 14 and eliminates crossovers 12 between coils of different  
6 phases, as shown in FIG. 4.

7                   Two design classes are practiced in the construction of single tooth  
8 windings, the first being single piece lamination with needle winding and the second  
9 being segmented stators. With regard to the single piece lamination with needle  
10 winding, this practice has the advantage that the stator laminations are whole or  
11 single piece, allowing easier assembly of the stator pack. Prestack stator packs are  
12 desirable for volume production. The windings are placed in the slots with a needle  
13 winder which somewhat restricts the available winding space.

14                  With regard to the segmented stator winding practice, there are many  
15 variations on this theme but all involve a segmented stator pack. The windings are  
16 wound in very high density either directly on the tooth or on separate bobbins and  
17 subsequently transferred onto the tooth. Bobbin winding requires some sacrifice of  
18 available winding area in order to get good layering, but very high density windings  
19 can be achieved. There is, however, an extra step of recombining the stator  
20 segments after winding placement.

21                  Stator connection refers to the process of linking all the coils in each  
22 of the phases. In a three-phase stator connection, a star-point is formed from the  
23 ends of the coils of each phase and the starts of the three phases are brought to the  
24 outside world as shown in FIG. 5. For small motors it is commonplace to terminate  
25 the start and finish of each coil on terminal posts.

## SUMMARY OF THE INVENTION

One embodiment of the present invention relates to a method for winding a stator of a multi-phase motor. The method includes successively winding each of a plurality of teeth on the stator with a continuous winding wire to connect each of the phases in the motor together. The wound wire is disconnected between any two phases where respective ends of the two phases connected by the winding wire are not neutral ends. A jumper wire is connected between a neutral end of any one of the phases to a neutral end of at least one other phase if the neutral end of that any one of the phase is not connected to the neutral end of that at least one phase by the winding wire.

## DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a perspective view of an 18-slot stator;

FIG. 2 is a diagram illustrating a conventional winding configuration for an 18-slot stator of a three-phase motor;

FIG. 3 is a diagram stator of a wound according to the winding configuration shown in FIG. 2;

FIG. 4 is a perspective view of a stator with windings that have been wound with a needle winder;

FIG. 5 is a circuit diagram illustrating the connections of phases in a three-phase motor;

FIG. 6 is a top view of a 9-slot stator illustrating a stator winding pattern in accordance with an embodiment of the invention;

FIG. 7 is a perspective view of a representation of the wound 9-slot stator shown in FIG. 6;

1                   FIG. 8 is another perspective view of the representation of the wound  
2 9-slot stator shown in FIG. 6;

3                   FIG. 9 is a diagram illustrating the winding pattern of the 9-slot stator  
4 shown in FIG. 6;

5                   FIG. 10 is a diagram illustrating a winding pattern of a 12-slot stator  
6 shown in accordance with another embodiment of the present invention;

7                   FIG. 11 is a top view of the 12-slot stator wound in the pattern shown  
8 in FIG. 10; and

9                   FIG. 12 is a diagram showing the electrical connections of the phases  
10 of the 12-slot stator wound as shown in FIG. 10.

#### 11                   DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

12                   The present invention is generally directed to a class of stator  
13 windings that has a stator tooth to rotor pole ratio (S/P) that is within the range of  
14 about 0.5 to 1.5. The invention can also be used with a stator designed for operation  
15 of the motor having voltage drive up to approximately 680 V DC.

16                   Referring to FIGS. 6-9, a 9-slot stator 18 for a motor having 6 rotor  
17 poles (not shown), for example, is shown in accordance with one embodiment of the  
18 present invention. The stator 18 is generally adapted to be used for smaller motors,  
19 typically, but not limited to less than 100 mm diameter, and includes nine teeth  
20 20-36 and nine slots 38-54 each provided between a pair of teeth (best shown in FIG.  
21 6).

22                   The stator 18 is also provided with an attached front-end insulator 56  
23 and a rear end insulator 58 (best shown in FIGS. 7 and 8) which, in one embodiment,  
24 is formed from molded engineered thermoplastic or similar material known in the

1 art. The rear end insulator 58 features a number of recessed pockets 60, through  
2 which a wire is routed for purposes of forming a connection by inserting a terminal  
3 into the pocket to provide an insulation displacement connection (IDC) and/or an  
4 interface termination at this point in the winding. The rear end insulator 58 also  
5 includes a system of slits having three different depths 64, 66, 68 (best shown in  
6 FIGS. 7 and 8) as an integral part of the molding. These slits 64, 66, 68 provide a  
7 mechanism for physically and electrically separating the sections of wire between  
8 successive coils 70 from each other, in order to provide a winding that has the  
9 capability to withstand high voltage.

10 A pattern for winding the stator 18 in accordance with one  
11 embodiment of the invention is now described. The arrows in FIGS. 6 and 9  
12 indicate the direction in which the wire is wound around the teeth 20-36. In one  
13 embodiment, the stator 18 is wound using a needle winder. Use of "in slot" winder  
14 or wire shooter are also contemplated. Referring to FIGS. 6 and 9, winding of the  
15 coils 70 starts at the slot 38, where a winding wire 72 representing a lead end U of a  
16 first phase is inserted through an IDC pocket 60 near the slot 38, and wound around  
17 the tooth 20 (between slots 38 & 40) in a clockwise sense. The wire 72 exits through  
18 the deepest end insulation slit 64 of the rear end insulator 58 at the slot 40 (see FIG.  
19 7 or 8). The winding wire 72 then loops over to the slot 44, routing the wire through  
20 the deepest end insulator slit 64 at the slot 44. The wire 72 is wound clockwise  
21 around the tooth 26, exiting through the deepest end insulation slit 64 at slot 46. The  
22 wire 72 then loops over to the slot 50, again routing the wire through the deepest end  
23 insulator slit 64. The wire 72 is then wound clockwise around the tooth 32, exiting  
24 through an IDS pocket 60 at the slot 52. This point corresponds to the neutral end N  
25 of phase 1 in the winding scheme.

Without interrupting the winding route, the wire 72 is routed through another IDC pockets 62 at the slot 52 (see FIG. 6). This section of winding wire 72 will later be sheared off in a post winding operation such that the winding reentry through the second IDC pocket 60 at the slot 52 now represents the start of phase 2, i.e., the lead end W. The winding wire 72 is wound around the first coil of phase 2 clockwise around the tooth 34, and routed out through the mid-depth slit 66 (best shown in FIG. 8) in the rear end insulator 58 at the slot 54. The wire 72 is then looped around the outside of the rear end insulator 58 and routed into the slot 40 through the mid-depth slit 66 at the slot 40, and wound around the tooth 22 in the clockwise direction. The winding wire 72 is then routed through the mid-depth slit 66 at the slot 42 and looped around the outside of the rear end insulator and through another mid-depth slit 66 at the slot 46, where it is wound around the tooth 28 in a clockwise direction, and exits through the mid-depth slit 66 at the slot 48. This position now corresponds to the neutral end N of phase 2. It should be noted that this, and subsequent section of the wire 72 overlaps a section forming phase 1, but since the routing slits 64, 66 in the rear end insulator 58 are at two different depths, these wire sections are physically separated.

Routing the winding wire 72 through the IDC pocket 60 at the rear of the slot 50, winding of phase 3 proceeds in reverse so that the current position corresponds to a joining of the neutral end N of phase 3 and the neutral end N of phase 2 (best shown in FIG. 9). The winding wire 72 entering the slot 50 is wound around the tooth 30 in a counterclockwise direction and routed out of the slot 48 through the low-depth slit 68 (best shown in FIGS. 7 and 8) formed in the rear end insulator 58 at the slot 58. It should be noted that although this portion of winding overlaps a section of winding wire 72 for both phase 1 and phase 2, a physical and an

1 electrical separation are maintained by the different depths of the end insulator slits  
2 64,66,68, thus maintaining high voltage integrity. The winding wire 72 is then  
3 looped in a counterclockwise direction and inserted into the slot 44 through the  
4 low-depth slit 68, where the winding wire is wound around the tooth 24 in a  
5 counterclockwise direction. Exiting through the low-depth slit 68 at the slot 42, the  
6 winding wire 72 is then looped in a counterclockwise direction into the slot 38  
7 through the low-depth slit 64 at the slot 34, where the winding wire 72 is wound  
8 around the tooth 36 in a counterclockwise direction. Finally, the winding wire 72 is  
9 then routed through the IDC pocket 60 at the slot 54. This point corresponds to the  
10 effective start of phase 3, i.e., the lead end V.

11               Once the wire 72 has been wound around all the teeth 20-36 in the  
12 manner described above, the IDC terminal 62 are inserted into all five pockets 60 to  
13 cut the winding wire at these points. Then, the portion of the wire 72 between the  
14 two IDC pockets 60 at the slot 52 is sheared, i.e., between the neutral end N of phase  
15 1 and the lead end W of phase 2, as indicated by a dotted line in FIGS. 6 and 9. A  
16 jumper wire 74 is attached between the IDC pocket near the slot 50 and the IDC  
17 pocket near the slot 52 which is electrically connected to the tooth 32 (best shown in  
18 FIG. 6). This step joins the neutral end N of phase 1 to the common neutral end N of  
19 phases 2 and 3 to make a star point connection as shown in FIG. 5. The remaining  
20 three IDC terminals 62 represent the termination interfaces or lead ends U, V, W of  
21 the three phases.

22               The present invention can also be described in connection with an  
23 embodiment shown in FIGS. 10 and 11, which is a stator 75 for a 10-pole rotor,  
24 12-slot stator motor (not shown), for example. The stator 75 includes twelve teeth  
25 76-98 and twelve slots 100-122. This embodiment illustrates a winding pattern in



1 which the individual coils 70 of a phase are not in simple series connection as in the  
2 embodiment described above. In this embodiment, with four coils per phase, the  
3 first pair of coils in series are parallel connected by jumper wires J1, J2, J3 to the  
4 second pair of coils which are also series connected. Those skilled in the art will  
5 recognize that in this arrangement each phase will have two neutral ends N, one for  
6 each pair of coils. This embodiment represents a more complicated routing of the  
7 wires but nonetheless represents the same principle that was implemented in the  
8 embodiment described above.

9 More specifically, as shown in FIGS. 10 and 11, the stator 75 is wound  
10 starting with a lead end U of the winding wire 72 being inserted into a slot 100  
11 through an IDC pocket 77 near a slot 122. From this point, the wire 72 is wound  
12 continuously from the tooth 76 to the last tooth 98 in the directions indicated by  
13 arrows on the wire 72 in FIGS. 10 and 11. In the order from start to finish, the teeth  
14 of the stator 75 are wound in the following order: Beginning from tooth 76 to 78 to  
15 82 to 80 to 84 to 86 to 90 to 88 to 92 to 94 to 96 and ending with tooth 98.

16 A jumper wire J1 is connected between the coils 70 formed from teeth  
17 76 and 88 to establish a parallel connection between the two sets of coils in phase 1.  
18 Similarly, a jumper wire J2 is connected between the coils formed from teeth 80 and  
19 92 to establish a parallel connection between the two sets of coils in phase 2. In  
20 phase 3 a jumper wire J3 makes the parallel connection between the coils 70 formed  
21 from teeth 84 and 96.

22 A jumper wire J4 is connected between one neutral end N of phase 2  
23 (from the coil 70 formed from the tooth 94) and the first neutral ends N of phases 1  
24 and 3 (the section of wire 72 extending between teeth 86 and 90). A jumper wire J5  
25 connects one neutral N of phase 3 (from the coil 70 formed from the tooth 98) and

1 the second neutral ends N of phases 1 and 2 (the section of wire 72 extending  
2 between teeth 78 and 82). In this manner, each of the two neutral ends N in one of  
3 phases 1-3 are electrically connected to a respective neutral end N in the other two  
4 phases as shown in FIG. 12.

5 A section of the wire 72 (indicated in dashed lines in FIGS. 10 and 11)  
6 connecting the coil 70 formed from the tooth 80 and the coil 70 formed from the  
7 tooth 84 is sheared to electrically isolate phases 2 and 3. Similarly, a section of the  
8 wire 72 connecting the two coils 70 formed from teeth 88 and 92 are sheared to  
9 electrically disconnect phases 1 and 2, and a section of the wire connecting the two  
10 coils formed from teeth 94 and 96 are sheared to electrically disconnect phases 2 and  
11 3.

12 In this embodiment also, the winding wire 72 is routed through the  
13 slits 64, 66, 68 with differing depth in the rear end insulator 58 (best shown in FIGS.  
14 7 and 8) to physically separate the wire between successive coils and between the  
15 phases. The recessed pockets 60 of the rear end insulators 48 are employed for  
16 purposes of forming IDC connections and lead ends in the winding. In this  
17 embodiment, the number of post winding jumpers to be inserted increases to 5, the  
18 number of sections of winding wire 72 to be sheared off increases to 3 and the  
19 number of IDCs employed increases to 13 as shown in FIGS. 10 and 11.

20 While various embodiments of the present invention have been shown  
21 and described, it should be understood that other modifications, substitutions and  
22 alternatives are apparent to one of ordinary skill in the art. Such modifications,  
23 substitutions and alternatives can be made without departing from the spirit and  
24 scope of the invention, which should be determined from the appended claims.

25 Various features of the invention are set forth in the following claims.  
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